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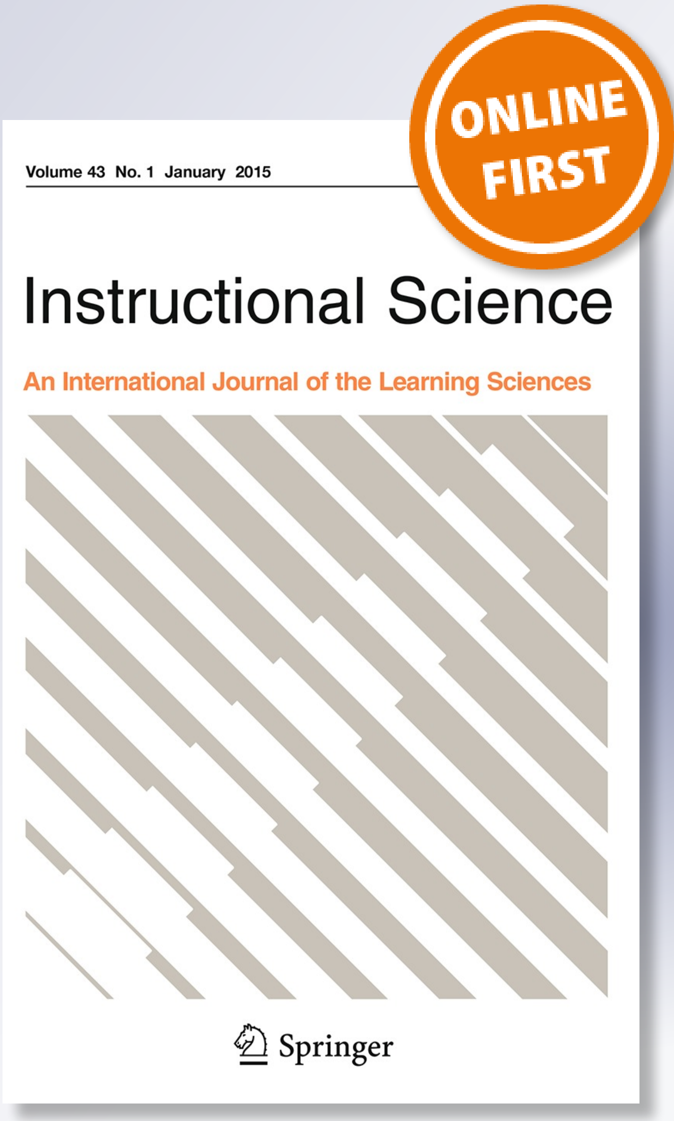

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# Teachers as participatory designers: two case studies with technology-enhanced learning environments

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**Abstract** Teachers are not typically involved as participatory designers in the design of technology-enhanced learning environments. As they have unique and valuable perspectives on the role of technology in education, it is of utmost importance to engage them in a participatory design process. Adopting a case study methodology, we aim to reveal in what ways teachers work as participatory designers and define conditions that support teachers in that. Two initiatives of participatory design in Canada and Singapore were investigated. Design materials, transcripts of design meetings, and interviews with teachers were qualitatively analyzed. Case study 1 (Canada) showed that two teachers participating in software design for an astronomy curriculum contributed by suggesting new design features, introducing pedagogical requirements, and providing feedback on prototypes or design ideas. It appeared essential that teachers feel that their ideas were valued and respected in the entire process. In case study 2 (Singapore), six teachers contributed to the design of a mobile learning trail through: Theorizing and bridging knowledge building principles, collaborative prototyping, contextual inquiry of activity relevance and activity execution, and collaborative evaluation of technology integration. Teachers valued case study discussions with similar cultural contexts and visiting the learning site to design with contextual knowledge. From our case studies, it can be concluded that teachers contribute

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to the design processes by engaging in theoretical discussion, active participation in a design partnership, reflection about pedagogy and practice, and experimenting with enactment. Conditions that support teachers include support in emergent processes and an atmosphere of trust and inclusion.

**Keywords** Teachers · Participatory design · Innovation · Mobile technologies · Professional development

Participatory design has emerged as an important methodology in a number of fields, including architecture, engineering, public health, community development, and education (Schuler and Namioka 1993). Typically, the participatory design approach has been used for the design and development of innovations that are tailored to end-user groups and contexts by including those users in various phases of the design process. Specific methods can include focus groups of stakeholders who discuss issues or critique design sketches, or observations of stakeholders engaged in normal practices to inform designs (Bødker and Iversen 2002). Suchman (1993) describes desirable outcomes of participatory design as "a more human, creative, and effective relationship between those involved in technology's design and its use, and in that way between technology and the human activities that provide technological systems with their reason for being" (p. viii). Subsequent to these early participatory design efforts, educational researchers have engaged teachers (Shrader et al. 2001) as well as students (Druin 2002; Könings et al. 2011) as participants in the design of educational innovations, guided by the reasoning that such inclusion will yield more ecologically appropriate, viable, and resonant materials and activities.

This article examines the engagement of teachers in the development of curriculum materials and software applications for purposes of classroom research. We are two different research teams, each of which includes teachers, researchers, and software developers, who collaboratively design and develop innovations for purposes of investigating new forms of learning and instruction (e.g., Cober et al. 2013; Peters and Slotta 2009). Over the years, both teams have learned the value of leveraging the knowledge and expertise of teachers (as well as other stakeholder groups) in design processes, and both teams have developed their own specific means and methods of helping these processes to succeed. Teachers tend not to be involved in the design of software applications—even those that are purposed for learning. It is thus understandably challenging for them to collaborate with researchers and software developers, and we are still learning how to best support their participation. Through two case studies, we will reveal the specific ways that teachers engaged in our participatory process, as well as some of the challenges, in order to understand how they might be better supported in the design process. We also want to understand the process of engagement from the perspective of the teachers, including what design activities and conditions they felt best supported their practice and professional development.

## Participatory design in educational research

Although the participatory design approach was not initially developed for applications in education (Schuler and Namioka 1993), its methodology has been influential in shaping current research practices that include teachers in design processes (Penuel et al. 2007). We begin by discussing the history and trajectory of the participatory design methodology, in order to show how it has come to influence our own work.

Pioneered in Scandinavia in the 1970s, the participatory design approach was championed by labor unions that were concerned that the presence of computers in the workplace would result in the automation and de-skilling of workers. Participatory design processes aimed to ensure a good fit between the expertise and practices of workers and technology implementation (Kensing and Blomberg 1998). Two guiding principles of participatory design are that (1) quality improves because end users are involved in the design process and (2) democracy of participation is ensured in all aspects of the design (Schuler and Namioka 1993). End-users are thus engaged in the design process in an effort to ensure the "use, usability, and utility" of a product (Shrader et al. 2001). In 1993, Muller and Kuhn began to formalize a participatory design methodology, detailing factors and processes that lead to successful design outcomes. Participatory practices were organized in a taxonomic space consisting of three dimensions: (1) Time during the development life cycle; (2) who participates with whom in what and (3) appropriate group size for the practice.

The fundamental ideas and features of participatory design have been applied in educational research, particularly for the creation of innovative teaching and learning practices, technological artefacts, and tools under educational reform goals. For instance, Shrader et al. (2001) made a case for "research for practice" as a design methodology in educational research, and detailed four characteristics that their approach shares with participatory design: (1) capacity building (2) theory testing (3) collaboration, and (4) focus on practice. Of these four characteristics, the first two are less relevant to our study. Capacity building is the idea that teachers can be empowered through professional development for school improvement. Although our participatory design work can indeed be a mechanism for capacity building, we did not collect long-term data to trace the trajectory of teachers' capacity building. Further, we do not discuss the characteristic of theory testing because the teachers in these case studies did not aim to examine the efficacy of a new theory of learning. The last two characteristics of research for practice are more relevant to the present paper, because they relate directly to our research questions. Collaboration is conceptualized as a mechanism through which the expertise of researchers and teachers is equally valued and through which each group can learn (Shrader et al. 2001). The expertise of teachers is highly valued, unlike "traditional educational research" where the locus of expertise resides within the academy. Further, every participant within the project is seen to have valuable knowledge and expertise. Participatory design is practice-focused because, "when teachers are involved in the design process, it is impossible to avoid discussions of the learners and teachers as end users of the designed product" (p. 4). Such a design process focuses team members directly and substantively on practice (Shrader et al. 2001). For example, design participants are likely to consider points at which the tool might present challenges and opportunities for learners, and then discuss ways that such concerns can be addressed. As with the participatory design approach, the "research for practice" perspective aims to ensure a good fit between technology designs and users of the technology.

Penuel et al. (2007) advanced the methodology of "co-design" as one that is well-suited for developing innovations for learning and instruction in real-world classrooms. In co-design, a dynamic partnership is formed among stakeholders, including teachers, researchers, interaction designers, and technology specialists. The co-design methodology aligns with the principles of design-based research (Brown 1992), because the innovation is carefully tailored to the classroom setting in which it will be investigated. The design team is engaged in an ongoing conversation about the innovation under development, discussing how it will lead to desired research and instructional objectives. Through a collaborative process, curriculum and supporting technologies are designed and developed, with the resulting innovations implemented within the participating teachers' own classrooms. Like participatory design and research for practice, co-design is concerned with ensuring a good fit between technology innovations and classroom practice. However, co-design differs slightly from a traditional participatory design approach, because the principal investigator takes on responsibility for ensuring success of the project. In a related approach known as Design Based Implementation Research, researchers and teachers work together to develop and evaluate solutions for real educational problems (Penuel et al. 2011). This approach differs from co-design because it is also concerned with developing innovations that can be implemented at a scale beyond one classroom or school (i.e., system wide).

Several studies have considered ways that teachers participate in the design of technology-enhanced learning environments. Lingnau et al. (2007) detail complementary action design, a process that brings together teachers, researchers, and developers, to leverage the expertise of these three groups. Peters and Slotta (2009) examine their co-design process in which researchers collaborated with two high school biology teachers to design a scripted wiki environment. Spikol et al. (2009) analyze their co-design process that included teachers, researchers, and developers for the development of mobile science application to support K-12 students in authentic practices of scientific inquiry, such as using sensors for data capture. They focus on the challenges that arose throughout process and recommend that design teams consider innovative design methods, such as the "Future Technology Workshop" (Vavoula and Sharples 2007). Zhang et al. (2010) discuss their approach and experiences in working with teachers to design a mobile curriculum for elementary science students.

The following two studies are examples of empirical research that closely examine the interpersonal dynamics of design participants within a design team for technology-enhanced learning environments that includes teachers and researchers. Reiser et al. (2000) describe a study in which teacher and university researchers collaboratively designed a technology-infused middle school science curriculum. This team used work circles to achieve their goal of mutual adaptation, to see a fit between external reform proposals and local conditions. The authors describe the tensions that arose between researchers and teachers, but state that the team's goal of mutual adaptation was achieved. Yoon et al. (2009)'s study sought to extend this work, by examining the mechanisms by which mutual design goals can achieved, using a lens of complex systems to examine how teachers and researchers can reach "convergent adaptive outcomes" (p. 272). This line of investigation (i.e., that which explores the interpersonal dynamics within a design team) has received less attention in the literature than studies that consider ways that teachers participate in the design process.

## Teachers as participatory designers: from design to implementation

Next, we present activities that describe teachers' participatory practices, as they might occur within a typical design process. In early stages, design teams often relate relevant experiences and share resources to build common understandings about research goals. For example, Zhang et al. (2010) report that before beginning to redesign ministry mandated curriculum materials, teachers related their classroom experiences of students who demonstrated misconceptions about science. Eliasson et al. (2011) describe preliminary activities that included addressing research goals and reviewing their own previous study's outcomes. In addition, many partnerships include discussions of theory and pedagogy early on in the design process (e.g., Penuel and Gallagher 2009; Zhang et al. 2010). Other examples of early stage activities include demonstrations of existing technological tools (Lingnau et al. 2007; Spikol et al. 2009) or workshops to highlight features of a device or program (Zhang et al. 2010).

After building shared understandings about research goals, teachers engage in brainstorming sessions with researchers to develop specific learning scenarios based on curriculum goals (Peters and Slotta 2008; Spikol et al. 2009; Zhang et al. 2010). Ideas from these sessions are captured using various technologies including word processing documents and concept maps (Zhang et al. 2010), yellow sticky notes (Spikol et al. 2009) and wikis (Peters and Slotta 2008). The documentation serves as a shared point of reference and is used to guide the ongoing design process. Other approaches include creating sketches and paper-prototypes of task and activity designs (Eliasson et al. 2011).

As the design work progresses, teachers may be called on to provide feedback to software developers regarding the layout and functionality of user interfaces (Eliasson et al. 2011) or to discuss practical issues of implementation, such as Internet firewalls (Lingnau et al. 2007). Before an innovation is fully developed, teachers may also play a role in using early prototypes with their students (Eliasson et al. 2011), allowing researchers to make advances in the technology designs through rapid iterations (Lingnau et al. 2003).

In addition to their engagement within the development phase of co-design work, teachers are asked to operationalize professional knowledge during the implementation phase of research projects. Carlgren (1999) advocates for a shift in thinking from "teacher as implementer to someone who actively constructs, invents, and designs the practice of schooling" (p. 50). Further, she contends that preparing and planning for teaching "is not something 'behind' or 'beneath' practice or action, but in the action" (pp. 51–52). Sawyer (2011) likens teaching to "an improvisational activity." He asserts that the best classroom teaching can be described as a "disciplined improvisation" where expert teachers re-create lesson activities within given structures and frameworks, to bring about effective and meaningful learning. Hence, the adoption of a participatory design approach with teachers also seeks to leverage their professional knowledge and regards teachers as discerning professionals who theorize, apply pedagogical principles, and improvise amid curriculum, cultural, and contextual constraints.

## Conditions that support teachers as participatory designers

From the literature, we can derive two conditions that support teachers as participatory designers: providing scaffolds to support teachers throughout the design process and emphasizing contextual knowledge. Brandt (2006) contends that in order to succeed, the participatory design process must be carefully orchestrated. This means that the process needs to be highly-facilitated such that teachers are presented with a clear set of objectives, activities, and milestones, with their role being clearly specified and supported (Roschelle et al. 2006). Muller and Kuhn (1993) also underscore the need for scaffolds—putting in place activities that befit specific contexts and needs, such as contextual inquiry for design, and collaborative prototyping and evaluation.

Knowledge of the context for use is imperative if teachers are to develop "usable" products (Shrader et al. 2001). Rather than controlling and excluding naturally occurring variables, the complexity of natural contexts should taken into account (Barab 2006). This means that the design team should closely examine the learning context—both social factors (such as characteristics of the learners) and the physical environment where the learning will take place. In his own research, Barab advocates for the need to design 'situationally embodied curriculum' to support learning in context (Barab et al. 2007). For instance, Squire and Klopfer's (2007) use of augmented reality allowed students to participate in the real practices of science investigation. This enabled students to acquire situated experiences about complex inquiry processes in real world contexts. Teachers need to be immersed in a relevant physical context throughout the design processes (e.g., located at the site where the innovation will be employed) in order to develop the contextual knowledge needed to design effective learning activities and software applications. This would also hold true for teacher learning and teacher engagement in a participatory design of technology-enhanced learning resources for use in the classroom.

## Research questions and overview of the case studies

Translating the key principles of participatory design into practice is a complex process, requiring the careful management of multiple roles, group dynamics and tensions. In this article, we argue that participatory design must center on the careful staging and structuring of the design process (Brandt 2006; Muller and Kuhn 1993), and that more needs to be known about how to invite and sustain teacher participation. At the same time, we view these processes as situated and emergent (Barab 2004; Cobb et al. 2003), and examine how teachers contributed throughout the process, from design to enactment of technology-enhanced learning applications. To this end, we adopted a case study methodology (Yin 2009) as an analytical lens to understand a complex mechanism related to structured, yet situated, and emergent practices that characterize the participatory design method.

To address the theoretical understanding of teacher participation in participatory design work, we articulate the following research questions:

1. In what ways did teachers participate in the design process?
2. From the perspective of the teachers in our case studies, what were the conditions that supported them in their participatory design work?

In the first case study, we explore the design participation of two teachers from a school in southern Ontario, Canada. Teachers contributed to the design, development, and implementation of a technology-enhanced learning activity for science inquiry within their own classrooms. The Ontario curriculum prioritizes the integration of information communication technologies into all subject areas (Toronto District School Board 2007). The designed innovation was enacted in a school that has a strong history of emphasizing student collaboration and inquiry-based learning. At this school, all teachers participate in weekly knowledge building meetings and have integrated this approach into their daily lessons.

The two teachers in this case study were members of a design team that consisted of researchers, interaction designers, and technology developers. The goal of the team was to support middle-school science students in their collective investigation of a digital astronomy simulation by providing them with the means to share observations, hypotheses and comments with all peers, in real time (Cober et al. 2013). The team designed a software application for use on tablet computers (e.g., iPads) and a companion interactive whiteboard (e.g., SMARTBoard). Figure 1 shows the application in use within the two classrooms.

In the second case study, we describe research that took place at a Future Schools in Singapore. With a state-of-art technological infrastructure and deliberately smaller class sizes, Future Schools are meant to serve as a forerunner in the use of emerging information communication technologies for teaching and learning, both inside and outside of the classroom. The design team consisted of researchers, teachers, and software developers who designed curriculum and technology-enhanced tools for mobile learning trails, for secondary school learners (see Fig. 2). One of the main goals of the design collaboration was to equip and empower teachers to integrate knowledge building pedagogies and practices (Hewitt and Scardamalia 1998; Scardamalia and Beretier 2006) into the technology designs for use on the mobile learning trails. The term "mobile learning trail" refers to an outdoor activity in which learners are equipped with mobile devices for the purpose of engaging in a collaborative form of inquiry (e.g., Chen et al. 2003; Sharples et al. 2007; Rogers and Price 2008).

The two case studies selected for this study, while conducted in different contexts, have several commonalities. In both cases, the teams adopted a participatory design approach and teachers were positioned as critical design partners. Although the teachers in both case studies were aware of the research agendas of the researchers, their objective was to meet curricular and pedagogical objectives. Design activities were structured to foster collaboration among all stakeholder groups, and the active involvement of everyone (including software developers) was encouraged. Teachers were involved in both pedagogical and technical design aspects of software applications and desired to ensure that the resulting innovation was a good fit for their students.

Both design teams sought to design and develop learning activities and technological applications that could support a knowledge building approach to instruction (Scardamalia and Beretier 2006). Knowledge building shifts the focus from individual knowledge construction to collaborative meaning making, in group or community settings (Scardamalia and Beretier 2006). The principles of knowledge building emphasize the continuous improvement of ideas with a belief that "what the community accomplishes will be greater than the sum of individual contributions" (Scardamalia and Bereiter 2003, p. 1370). This approach gives students a high level of agency and responsibility for developing their own questions, exchanging and critiquing ideas with peers, and even evaluating their own progress. Often, this knowledge is situated within a technology-mediated environment that scaffolds students as they add new ideas, revise materials, or synthesize new arguments. For the Canadian case study, the design team wanted the software application to make visible the progress of student ideas, and to support students in knowledge building discussions about a shared phenomenon of interest. For the Singapore case study, the aim was to acquaint students with situated collaborative knowledge building practices and to scaffold students using a technology-mediated environment, toward explicit idea sharing and productive discussions.

There are also several differences between the case studies. The Canadian case focused on designing a technological application for use within the classroom context, whereas the Singapore case centered on designing learning activities for use outside of the classroom. The level of teachers' understanding and enactment of knowledge building pedagogy also differed, requiring different ways to scaffold teachers' pedagogical understanding. The Canadian teachers were already deeply committed to a knowledge building approach (i.e., prior to their involvement in the research), and it had been a central aspect of their teaching


**Fig. 1** The product of the design team's work for case study #1. *Left* The interactive whiteboard and tablet applications. *Middle* and *right* The tablets and interactive whiteboard applications in use in the classroom


**Fig. 2** *Left* The product of the design team's work—the mobile learning trail application in case study #2. *Middle* Design meeting held at the Future School site. *Right* Design meeting held at Fort Siloso, site of mobile learning trail

practice for many years. In contrast, because the Singapore teachers were new to knowledge building, discussions about the pedagogical perspective were much more intrinsic to the design work.

## Case study 1: embedded phenomena in the elementary classroom (Canada) method

### Participants

The design team consisted of three stakeholder groups:

1. Researchers (Authors Cober and Slotta) from two North American universities.
2. Two sixth grade classroom teachers from an elementary school in a large urban center in Ontario, Canada;
3. Software developers from two North American universities.

The teachers, Brad and Jennifer (pseudonyms) were veteran users of technology-enhanced materials in their classrooms. At the time of this study, Brad and Jennifer had 7 and 3 years of teaching experience, respectively. Although these teachers had participated in studies with other research groups, the design process that is the subject of this article was the first one in which they engaged with our research group. Brad and Jennifer were selected because (i) they work at a laboratory school that has formed a research partnership with our Ontario University, and (ii) because they teach grade six, and students who are ages 10–11 are an appropriate age group for the existing inquiry environment (see "Materials" section) that we applied and extended.

## Materials

The design team applied and extended an existing inquiry environment known as Helio-Room (Moher 2006), in which students participate in a whole-class investigation of a dynamic simulation of our Solar system. Digital representations of planets from our Solar system (in the form of equally-sized colored circles) are seen to orbit at various speeds around the classroom, visible on one screen before moving to the next. There are four screens positioned around the classroom. Over the course of a 90-min period, students work together to identify the planets, drawing on their observations of the planets' occlusion relationships and differential speeds.

The design team's goal was to create a software application that would allow students to contribute observations concerning the occlusion relationships of the planets (e.g., to state which planet passed in front of which other planet) and the relative speed of the planets. The design team desired to make the activity manageable for teachers and students alike, by creating software that produced aggregates of every student's contribution, showing observations by planet color (see Fig. 1). The aggregates made disagreements in the students' observations visible, and provided a focal point for class discussion. This system was accessible throughout the activity, with contributions appearing in real-time on students' tablet computers and the classroom interactive whiteboard (Cober et al. 2013).

The design team used technologies to keep a record of design discussions. A Google document, to which all members of the design team were given editing permissions, was created to initiate discussion about possible directions for the software design. This technology was chosen to accommodate the teachers' busy schedules, as it could be read and commented on at their convenience. Researchers created and maintained a design wiki, which contained a record of the date, attendance, and a description of design ideas that were discussed during each meeting. Researchers used it to house their field notes, photographs, and digital mockups.

## Procedure

The teachers participated in four face-to-face meetings over two months. They also used online communication to contribute throughout the design process (e.g., through emails). Each face-to-face meeting was about 90 min. Along with the entire design team, the teachers shaped the design and implementation of the technologies in three ways: (I) They contributed to a shared Google document that allowed for simultaneous editing; (II) they participated in design meetings with researchers and technologists; (III) they actively participated in a debrief meeting between classroom sessions (e.g., on the days of implementation). A brief description of each activity follows, with more information about the design process given in "Results" section.

The Google document was intended to elicit teachers' comments on possible directions for designs. To get the process started, researchers seeded the document with three headings: "Kinds of knowledge objects", "Kinds of scaffolding", and "Kinds of technology". The researchers encouraged the teachers to add their comments and ideas to the document. The document was frequently referred to during design meetings and emails. Teachers made comments and edits to this page, providing a valuable source of input and feedback into the design. The face-to-face meetings with the teachers took place at their convenience and were held on school property. The two classroom enactments took place on the same school day. After the first enactment in Brad's classroom, a debrief meeting was held with all members of the design team present. All members of the design team (including Jennifer), observed the morning's class. Although this was not a design meeting per se, the debrief session played an important role in shaping the afternoon activities. The debrief meeting is not a focus of analysis, but we mention it here because the teachers referenced it in their interviews.

## Data analysis

To address the first research question concerning the ways in which teachers participated in the design process, we examined two kinds of data: Design documentation (Google document, design wiki, and emails) and teacher interviews. Using the revision history feature of the Google document, we looked for edits that were authored by the teachers. We made note of their authorship, content, and the date of authorship. We examined the meeting minutes contained within the design wiki and email correspondence with the teachers, and made a list of the contributions made by the teachers. Using these data, we created a timeline of design events in which teachers participated. Through examination of these data, three modes of teacher participation emerged. In addition to examining design documentation, we examined interview transcripts in order to understand teacher design participation. After the enactment, Brad and Jennifer participated in separate 90-min interviews, conducted by a senior researcher in our group who is also an experienced classroom teacher. This researcher is not an author on this paper and did not analyze the interview data. The interviewer asked two questions that are particularly relevant to this study: (1) how did working within this research collaboration influence your practice? and (2) How can we improve the process? The transcripts of these interviews were analyzed using an open coding approach to analysis (Creswell 2013). We read through the transcripts, looking for excerpts where teachers referenced their participation in the design process. We extracted 22 excerpts. To maintain the integrity and context of the quote, an excerpt began at the first mention of the teacher's design participation, and ended when that line of thought concluded. These excerpts fell into two sub-categories: (1) participation in the design phase (i.e., during design meetings), and (2) participation immediately leading up to and during the implementation phase (i.e., during the debrief meeting and during implementation in the classroom). We reviewed the excerpts in each subcategory, and an additional six modes of participation emerged, three from the first sub-category and three from the second sub-category. Extracts were coded with one or more mode of participation. As we will discuss in "Results" section, there was some overlap in the modes of participation that were revealed through study of the design documentation and from the interview transcripts. In total, from our data we derived nine modes of teacher participation and four conditions that supported their design process.

To address the second research question concerning the conditions that supported teachers in their design work, we examined the interview data only. We reviewed the transcripts again and looked for excerpts where teachers critiqued or analyzed the design process. An excerpt began at the first mention of conditions that supported teachers in their design work and ended when this topic concluded. We extracted nine excerpts and derived four conditions that supported the teachers' design work. Extracts were coded with one or more supporting condition.

## Results

### How teachers participated in the design process

Because teachers crave efficiency, Jen often delegated to Brad the responsibility of summarizing their joint responses to issues and provided their joint input to the design. Early in the design process, Jen mentioned that she would meet frequently with Brad in the mornings or afternoons about particular issues, then leave it to him to write their joint response. Many emails were sent from Brad's e-mail account, but signed "Brad and Jen". We came to trust that their two voices were represented equally in all contributions to the design documents. Brad became a de facto secretary of the teachers' ideas, and hence analysis of the document's edits history showed that all of the teachers' edits were made from his account. But all ideas entered into the document were considered as having originated equally from the two teachers, both because this was their stated intent, and because this practice matched well with the high level of communication and collaboration that was known to exist between them. Our analysis of the Google document and the design wiki revealed the following modes of teacher participation: (i) suggesting new design features; (ii) introducing pedagogical requirements (e.g., the need for open-ended discussion); (iii) providing feedback on design ideas and prototypes.

The teachers contributed ideas through online tools and in face-to-face discussion. The teachers added six comments to the shared Google document in response to ideas that had already been advanced by researchers. For example, they suggested that students should be prompted to give a reason, theory, or evidence for agreeing or disagreeing with an observation. In the final application, students were given space to give a reason for their observation (in the form of evidence or a theory), but were not prompted to do so. In another comment the teachers speculated that students would be motivated by the possibility of reading the observations and comments of their peers in real time. In a third comment the teachers advised that the application steer away from "incentive" type rewards, such as points, because they had found this approach to be discouraging for some of their students. The final application, therefore, did not use any sort of incentive system. Researchers responded to the teachers' comments within the Google document, offering affirmation and adding on to their ideas. Figure 3 presents a timeline detailing teacher design participation.

At the first meeting, the teachers suggested several important design ideas, including the need for students to engage in open-ended discussion, a feature that later became part of the software application. At the second meeting, the teachers viewed a series of low-

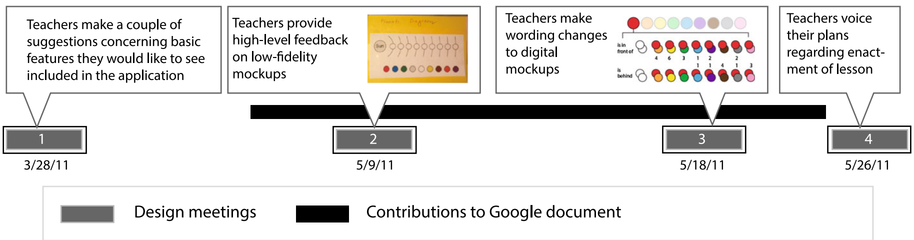


**Fig. 3** A timeline showing a summary of the teachers' participation in the design process. Low-fidelity prototypes are shown in the *box* for meeting #2; digital mockups are shown for the *box* in meeting #3

fidelity prototypes (i.e., mockups created using colored paper and sticky notes) that portrayed initial design ideas. The teachers provided high-level feedback on these early designs, weighing the pedagogical implications of the various options. These contributions were instrumental in the team's final design commitments. In the third meeting, researchers presented the teachers with digital mockups of the interface design. Again, the teachers weighed in, fortunately affirming that the design seemed right, but suggesting small changes in wording, such as the header on student pages. In the fourth meeting, which occurred just before implementation, teachers provided feedback on the use of particular features of the application and voiced their ideas concerning the ways that they would introduce students with the software tool (e.g., sequencing of instructions).

The interview data reveals the following modes of design participation from the perspective of the teachers: (i) Contribution to design documentation; (ii) participation in discussions concerning technology implications; (iii) contributions to discussions about pedagogy. Pedagogical discussions were stressed the most, followed by discussions concerning technology implications, and contribution to design documentation. Brad spoke about the contribution that he and others on the team (i.e., researchers) made to the Google document. "It was purposeful that way. It had tons of information, and tons of value, but it wasn't finished. And then everyone on the team, including the teachers—steps forward." Jennifer spoke of her participation in design meeting discussions concerning the implications of the technology designs, and how the team grappled with details, such as "how one constraint in the program is going to affect student questioning." She also spoke about design discussions that pursued higher-level pedagogical concerns, such as "the philosophical meaning of knowledge building."

From the excerpts that related to teacher participation just before and during the implementation phase the following modes of participation emerged: (i) planning how they would implement the technologies; (ii) discussing how the technology would be implemented differently in the second classroom (i.e., Jennifer's) during the debrief session; (iii) reflecting on implementation. The teachers did not stress one mode of participation, and discussed all modes with the same frequency.

Brad spoke about how he had rehearsed his plan internally before going into the classroom: "It was a [lesson]—and filled with a lot of teacher work, with new materials, and different things. I felt like I had that score (to use a musical metaphor)… in my head when I walked in." Both Jennifer and Brad discussed their roles in the debrief session. Jennifer stated that her involvement in the debrief meeting allowed her to make significant changes to the instructional design. She explained that she made a deliberate choice to introduce the technology in a way that was different from Brad: "[I did it] in a way that just said, 'Without very much scaffolding from the teacher and simply putting the technology into the students' hands, what do they do? What's their level of engagement? What misunderstandings come? What parts of the technology might be confusing if it isn't scaffolded in a very comfortable way?" Brad recalled their motivation for making a change in the second enactment: "What we were doing was experimenting with the timing [and] degree of teacher intervention." Both teachers spoke about the importance of reflection in the design process. Jennifer said: "I feel like all of us could sit around a table for days, and talk the ins and outs of education and this project, and always come up with new and better ideas."

Thus, the teachers' discussion of their role during the design phase was consistent with our analysis of the design documentation. In their interviews, the teachers stated that their participation was of a pedagogical nature, which is in keeping with our category of "contributions to discussions about pedagogy." Similarly, the teachers remarked that they had suggested new design features, which relates to our category of "contribution to design documentation." Finally, the teachers commented that they had given feedback on prototypes or design ideas, which is within our category of "discussions concerning technology implications."

### Conditions that supported teachers in their design work

Our analysis of the interview data revealed the following conditions that support teacher design participation: (i) feeling of inclusion, (ii) feeling of trust and ownership, (iii) a process that feels natural, (iv) perception of ideas being valued. These conditions were derived from the nine excerpts that related to conditions that supported teachers in their design work. The condition codes were distributed evenly across all four conditions. Both teachers said that they had felt a strong sense of being part of the process and spoke about a feeling of trust. Jennifer articulated that there was an understanding that existed among the entire team: "We don't have this major divide between…you know, technology designers, researchers, and teachers, because in so many ways, I think our understanding of pedagogy at least philosophically, are on a very similar level." Jennifer said she considered the group to be "a very safe group of people" to work with. Brad said, "It has been kind of magical working with this research group because, when [author, and principal researcher] said in the earlier going, that we would be part of the design team, that would be an easy thing for researchers to say in a lip service 'We are going to take into account the things that you say'… But I quickly figured out that he really meant that." Finally, both teachers stated that the process and also the final innovation felt "natural" to them. Jennifer stated, "It makes us feel really comfortable and really…natural for us to be with a group of people who are that committed to making sure it fits our students' needs."

Our analysis of these excerpts revealed that the team dynamics, including respect and trust, resulted in an experience that was positive for the teachers. These matters are addressed further in "Discussion" section.

## Case study 2: design of a mobile learning trail (Singapore) method

### Participants

The design team consisted of three stakeholder groups:

1. Researchers (authors So and Tan) from a large university in Singapore.
2. Six secondary school teachers in integrated humanities (i.e., history and geography) from a Future School in Singapore;
3. Three software developers.

Four of the six teachers on the team were the pioneers of the Future School mobile learning project and had designed resources for two previous iterations of the mobile learning trail. There were four concurrent projects in the school on different core subject areas (i.e., Languages, Math, Science and Humanities). Hence, all the teachers in the school were involved in one of these four projects. This case study focuses on the six teachers of the Integrated Humanities department who participated in our project focusing on mobile learning approaches in and out of school. As Future School teachers, they were savvy users of technologies for teaching and learning. At the time of our study, all six teachers had between 3 and 5 years of teaching experience in their respective subject areas.

Materials

The design team worked to create curriculum materials for a mobile learning trail that would be used by students at Fort Siloso on Sentosa Island, Singapore. Fort Siloso is a restored coastal gun battery and the site of a significant World War II battle. The goal of this innovation was to provide students with a rich learning experience through scaffolding their exploration of the historical battle site using a learning environment for handheld devices.

The design team's goal was to devise activities for the mobile learning trail that would integrate the study of both history and geography. The six teachers wanted to ensure that students had the opportunity to evaluate the physical features of the landscape in relation to historic events that occurred at the site, through the completion of inquiry tasks at each of the four activity stations at Fort Siloso. By experiencing the geographical location and the physical features of Sentosa Island firsthand, students would be able to explain the motivation of British forces for choosing Fort Siloso as a site of defense during the Japanese invasion of Singapore in 1942.

The design team created a web-based tool that consisted of applications and cognitive tools (e.g., digital maps, iPad apps). Students used the tool to undertake collaborative inquiry activities at four stations at Fort Siloso (e.g., tunnel complex, gun embankment area, mid-cliff area, and fire direction tower). Scaffolding prompts were designed to provide guidance as students interacted with the rich physical affordances of the learning trail site. For example, when students entered the tunnel complex, the application prompted them to describe the dimensions of the tunnel, explain why the tunnels were necessary, and describe the purpose of the tunnels. The platform included both a private and public space. In the private space, students could record their groups' collected data and findings relating to the mobile trail activities. In the public space, learners could solicit feedback or comments on their ideas and findings from their peers. In addition, the public space feature allowed teachers to provide immediate feedback and facilitation remotely to students during the enactment of inquiry activities on the mobile learning trail.

Procedure

The design team met eight times over a period of two months. Five meetings were held at the Future School site and three meetings were held at the Fort Siloso location. The duration of each meeting was from 1 to 2 h. The four main phases of the design process are described below: Reflection on the previous year's learning trail design, discussion of related case studies, development of the mobile learning trail and resources, and participation in walk-throughs of the mobile learning trail.

Through plenary discussion, the design team reflected on the previous year's enactment of the mobile learning trail by eliciting comments and feedback from the teachers. The design team then considered possible refinements to the mobile trail structure and discussed how the new curriculum and technology designs might better foster knowledge building practices and critical thinking skills. In small groups (a mix of geography and history teachers), the design team engaged in discussions that stemmed from the review of related case studies about how knowledge building pedagogy was adapted and practiced in Japanese (Oshima et al. 2006) and Hong Kong (Chan 2008) classrooms. Researchers led discussions on the integration of topics and lesson procedures to support knowledge building discourse. Using graphic organizers, the geography and history teachers worked in small groups to develop the curriculum and activities that would be integrated into the software application, in order to ensure sound integration of topic areas, concepts, and skills. The teachers participated in walk-through of the mobile learning trail. The team referred to these site visits as "recces" (i.e., reconnaissance missions) because they involved visits to the actual site of implementation. These visits provided the team with an opportunity to partake in activities from the perspectives of learners and to potentially preempt problems that could arise from the use of the technology.

## Data analysis

We draw on three sources of data for our analysis of the Singapore case study: Researchers' field notes, transcripts on design meetings and transcripts of teacher interviews. Two researchers (Authors So and Tan) conducted semi-structured one-to-one interviews with the six teachers regarding their overall experiences in the design process,

**Table 1** For each discourse code, we provide a description of the activity and an example of coded discourse

| Discourse code | Description of activity | Example of coded discourse |
|---|---|---|
| Theorizing knowledge building principles | Discussion of knowledge building principles and how they relate to key constructs of collaborative learning and critical thinking in the context of the mobile learning trail | Teacher: "One of the key things about knowledge building is being able to build from somebody's ideas" |
| Bridging knowledge building principles | Discussion of knowledge building pedagogy using case studies from Japanese and Hong Kong classrooms as a basis for discussion. In small groups, teachers discuss how knowledge building principles might be applied to current curriculum designs | Teacher: "When we plan that activity that is structured based on knowledge building, at any one time, how many of these principles must we include?" |
| Collaborative prototyping of knowledge building activities | Use of graphic organizers to organize the development of driving inquiry questions that are specific to each of the four stations on the learning trail | Teacher: "For the trail activity we can use Sentosa island. The post-trail activity can also be a real world example" |
| Contextual inquiry of activity relevance | Posing of questions to each other, making reference to physical affordances of Fort Silo site, with the goal of establishing the relevance of activities and sound integration of content knowledge for both subjects | Teacher 1: "Why is there a need to measure from here to there?"<br>Teacher 2: "To calculate the amount of time needed…" |
| Contextual inquiry of activity execution | Walk-through of the mobile learning trail activities to evaluate if they are appropriate for learners and to determine if the connections between subject content and the physical learning context are clear | Teacher to software developer: "We need to create context, persona, and scenario for each activity station" |
| Collaborative evaluation of technology integration | Pilot-testing and evaluation of the applications that had been developed for the mobile learning trail | Teacher to software developer: "The stealth boat is supposed to be on the digital map" |

and issues/challenges encountered for improvement. While the researchers conducted the individual interviews, the teachers were forthright about their feedback and suggestions since they understood the importance of the progressive refinement of this Future School project, which were meant for scaling up and translation.

To answer the first research question, concerned with the ways in which teachers participated in the design process, we examined researchers' field notes and design meeting transcripts. In our analysis, we focused on four of the eight design meetings, selected to encompass the complete range of design activities—from early knowledge building discussions to pilot testing of the applications in situ. Using both researchers' field notes and transcripts of design meetings, we created a timeline detailing the ways in which teachers participated in these four meetings. We performed discourse analysis using the transcripts of the design meetings, dividing the transcripts from the four meetings into 26 episodes that were demarcated by semantic boundaries. All discourse items contained within any thread of discussion were kept within a single episode. Each episode formed one unit of analysis and could contain more than one discourse code. For our coding scheme, we selected activity codes from Muller and Kuhn (1993) that were relevant to our design process, such as collaborative prototyping, contextual inquiry, and cooperative evaluation. To that list, we added two additional codes that were particularly relevant to our research context: Theorizing about knowledge building principles, and bridging knowledge building principles and practices. Using this coding scheme, we coded the discourse contained within each episode (Table 1 in "Results" section).

To answer the second research question concerning the important conditions that supported teachers in their design work, we analyzed transcripts of teachers' discourse in design meeting and interviews, using an open coding scheme to produce a thematic analysis. The results of research question 2 are thematic and are not organized by design meeting.

## Results

### How teachers participated in the design process

Table 1 shows the discourse codes that emerged from our analysis of the design meeting transcripts. These codes are one outcome of our analysis, as they serve to bind the

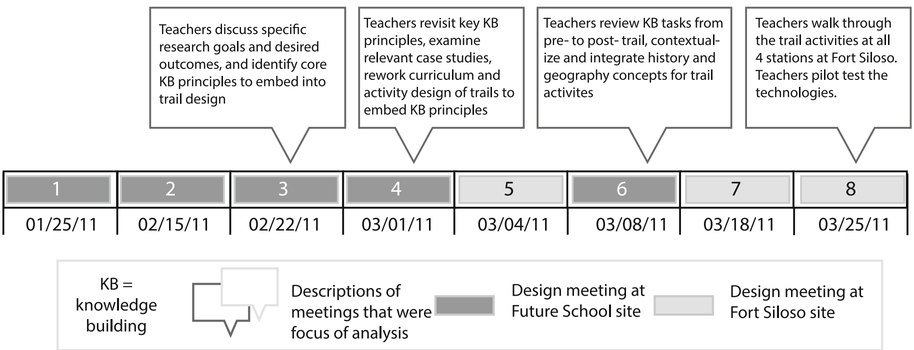


**Fig. 4** A timeline showing a summary of the teacher participatory practices in the design process

qualitative description of teacher engagement. They were then applied as a coding scheme of the specific activities in which teachers engaged.

Next, we present a timeline detailing teacher design participation in the four episodes that we analyzed, drawing from researchers' field notes and design meeting transcripts (see Fig. 4).

Figure 5 presents a comprehensive overview of the discourse types that teachers engaged in for each episode that we defined in the participatory process. Overall, we found that although teachers' involvement was relatively high throughout the different phases of the design cycle and activity types, their active participation, as indicated by the discourse analysis, increased towards the end of the design cycle in the site visits and walk-through activities. Next, teachers' participation varies in relation to the design context (i.e., school or Fort Siloso), discourse types, and participating stakeholders.

Overall, our analysis of the teachers' discourse from four meetings revealed several important dimensions concerning teachers' participatory practices in the design process: (1) theory-driven (e.g., theorizing knowledge building principles, bridging knowledge building principles); (2) application (e.g., collaborative prototyping of knowledge building activities, contextual inquiry of activity relevance, contextual inquiry of activity execution); and (3) evaluation (collaborative evaluation of technology integration). Each dimension is explained in the meeting data below.

Analysis of discourse in the first meeting (see episodes 1–3 in Fig. 5) showed that teachers' participation was fairly even across the first three codes (theorizing and bridging

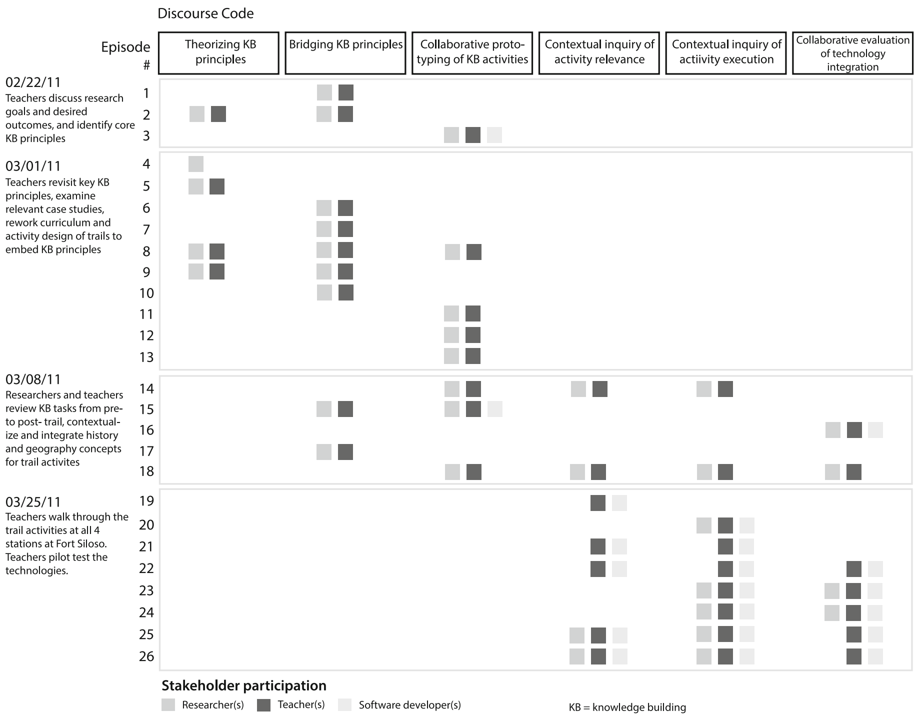


**Fig. 5** Summary of teacher participation in relation to the discourse types, design, and other stakeholders across the 26 coded episodes

knowledge building principles, and prototyping knowledge building activities). The focus of this meeting was discussion of knowledge building pedagogy, where researchers discussed the main ideas of knowledge building pedagogy, showing how they are related to collaborative learning and critical thinking in a mobile learning context. Examination of the transcripts showed that teachers regarded the translation of theoretical principles into classroom practices as both challenging and imperative. This could account for the two episodes of bridging knowledge building principles and practices to embed core knowledge building principles into the design of the mobile learning trail before teachers proceeded to design prototype activities with software developers in episode 3.

In the second meeting, the design team revisited key knowledge building principles, examined relevant published case studies, and endeavored to integrate these principles into the activity design of the mobile learning trails. Here we defined ten episodes (see episodes 4–13 in Fig. 5). The distribution of the teachers' discourse showed an increase of teacher participation in the bridging of knowledge building principles and collaborative prototyping of learning trail activities. Analysis of the discourse showed that teachers applied their theoretical knowledge to the design of learning trail activities, with reference to previously published case studies. Teachers also actively engaged in the collaborative prototyping sessions with the researchers, where they designed learning activities to guide the knowledge building process, creating small inquiry tasks for each of the four learning stations. These activities were designed to enable students to enact knowledge building principles: Generating diversity of ideas, identifying and expand relevant ideas, and creating high-level summaries of the best ideas. The discourse in this meeting continued to relate to understanding and applying knowledge building principles. Software developers were not present at this meeting.

The third meeting we analyzed (see episodes 14–18 in Fig. 5) took place after the first "recce" at Fort Siloso. Teachers' discourse was coded in all categories except for theorizing knowledge building principles. This recce trip served as an essential bootstrapping event in the design process, enabling discussion to move from design of activities that are infused with knowledge building theory and principles to more context-driven discussions. The physical affordances of the meeting place played a critical role in this transition. In order for the teachers to integrate principles of knowledge building into the learning trail activities, they needed to have deep contextual knowledge of the learning environment. Discourse analysis showed that teachers came to understand that the activities that they had planned prior to the site visit did not fully leverage the physical affordances of the environment. The teachers' adaptation of knowledge building principles was contingent on familiarity with physical features of the learning environment. Hence, this finding indicates that the context of the design meetings influenced the discourse types, enabling the design team to move from theoretical discussions to discussions that applied theory in a specific context.

In the fourth meeting, teachers walked through the learning trail activities at all four stations at Fort Siloso, working closely with the software developers to pilot test the technologies that had been designed to support the mobile learning trail activities. Discourse analysis showed that as the design context moved from school to trail site (see episodes 19–26 in Fig. 5), discourse focused entirely on the relevance of the learning activities as they related to the physical context of the learning environment, execution of the technologies, and evaluation of technology integration. This finding underscores the importance of the pilot-test, which could only have taken place at the trail site.

The analysis of the four meetings reveals that teachers' participation varies in relation to the design context (i.e., school or Fort Siloso), discourse types, and participating stakeholders. Corresponding with the agenda for each meeting (e.g., discussing relevant case studies), teachers participated in discourse that helped to move curriculum development forward. When the context of the design meetings shifted to site visits, the discourse of the teachers spanned both theory and practice. When teachers participated in the walk-through exercise, their attention shifted again and became focused on the contextual inquiry and technology integration.

The shift in discourse types is also contingent upon the stakeholders' presence. In the earlier episodes (see episodes 1–10 in Fig. 5), discourse took place mainly between researchers and teachers in theory-driven activity types such as theorizing knowledge building principles and collaborative prototyping of knowledge activities. When discourse occurred primarily between teachers and software developers (see episodes 19, 21 and 22 in Fig. 5), discourse types centered on context-driven activities such as leveraging contextual affordances and integration of technology designs within the learning environment. It is apparent that teacher participation in the design process hinges on both their contextual knowledge of the learning environment and the professional expertise of other stakeholders.

## Conditions that supported teachers in their design work

Analysis of both teachers' discourse in the design process and the narrative interviews showed three important conditions that successfully supported teachers in the participatory design process: (1) provision of other case studies for the purposes of adapting them to the current design context, (2) consideration of contextual knowledge of the learning environment, and (3) leveraging the expertise of other key stakeholders in the design process.

The teachers stated that studying other case studies in light of the current design context was a useful component of the design process. The transcripts of teachers' discourse showed that they regarded the translation of theoretical principles into both classroom and mobile learning context, as both challenging and imperative. In one-to-one narrative interviews following the design process, four of the teachers expressed appreciation for the provision of a case-study approach. Two of them requested more of the same kind of sessions. One teacher elaborated, saying that she enjoyed "using case studies on how knowledge building has been worked out in an actual context—in educational systems more similar to Singapore at large."

The teachers stressed the importance of the role of being physically immersed in the Fort Siloso environment, and described how this activity resulted in deep contextual knowledge. The contextual knowledge afforded the teachers greater coherence between geography and history in the progressive refinement of the design of the learning activities. A geography teacher remarked that the "recce trips were necessary to see what could be achieved at each station… to analyze how both subjects could lend content to each other." Similarly, a history teacher observed, "Much effort was put into contextualizing the activities to incorporate both history and geography in the best natural way." Teachers operationalized their contextual knowledge by requiring students to synthesize both geography and history skills and knowledge at each of the four learning stations.

It is apparent that teachers' discourse with other stakeholders is related to the participatory practices, and that the teachers leveraged the expertise of these stakeholders. Teachers appreciated the presence of software developers during the simulation of the learning activities and the technological tools. Two of the teachers shared how the technological tool and platform "increased the proximity of the learners to the object of inquiry, allowed students mobility, but at the same time enabled us to capture their learning". Teachers were able both to give students greater autonomy in the learning journey, and to monitor their learning progress through the communication and feedback channel. Further, the participation of the researchers at both the school context and trail site was pivotal to help teachers design knowledge building activities for a mobile learning trail. One teacher commented on the smaller inquiry tasks that were guided by the overarching big question that "the nature of the questions made it more viable to do critical thinking, to leave things open ended with scaffolding." The teachers felt that the platform and the activities have created the space for knowledge building experience in an outdoor learning environment. Also, the teachers noticed that the occurrence of knowledge building discourse took place not only on the digital platform, but also via face-to-face discussion where students share information and negotiate meanings with other groups during the trail.

## Discussion

First, we discuss some of the common roles played by teachers in the design process in our two case studies, followed by a review of the conditions that support teachers' participation. While many of these common factors echo the existing literature, this study provides a detailed and cross-cutting account of two current cases in the learning sciences, which we hope will inform others who wish to adopt a participatory design methodology.

### How did teachers participate in the design process?

The teachers in our two case studies played a vital role in the design process—participating in preliminary discussions to address research goals, providing input and feedback into designs-in-progress, reviewing outcomes of prior efforts, and debriefing with the team during the implementation itself. In both cases, they were designing for their own classrooms, which provided excellent incentive for participation. To the extent that we could successfully engage them and effectively incorporate their input, we could have greater confidence that our innovations would succeed. We describe four ways that teachers participated in the design process: Engaging in theoretical discussions, active participation in a design partnership, reflection about pedagogy and practice, and experimenting with enactment.

Early in the process, both of these case studies revealed the use of theory-driven discussions to ground design work. This is consistent with Zhang et al.'s (2010) study that through such discussions "two parties seek to understand each others' perspectives, so as to produce contextualized materials" (p. 1506). Prioritizing theory-driven discussion within the design process is critical, because it brings to the surface underlying theoretical convictions of design team members. By making pedagogical agendas (Svihla et al. 2015) explicit, the design team can move forward and make purposeful decisions concerning technological features that support theoretical positions.

The teachers in both case studies were active participants in multidisciplinary design partnerships. Teacher input during design discussions served to guide the designs, and ideas were captured using various technologies including a Google document in the Canadian case and graphic organizers in the Singapore case. We suggest that it is important to provide asynchronous tools such as Google documents which can support the flexibility and continuity of communication between teachers and researchers.

A critical element in effective design partnership is the cultivation of positive working dynamics between members of different disciplinary groups within the design team. Although these dynamics were not a focus of this paper, it was apparent that the interaction of teachers with other stakeholder groups impacted their role as a member of the design team and their experience of it. In the Singapore case, teachers actively engaged with software developers, especially during the pilot-testing phase at the mobile learning trail site. These exchanges were essential for creating a coherent final application. The Canadian teachers did not interact with software developers a great deal.

In both case studies, teachers made important pedagogical contributions not only to the technological features of the design, but also to its pedagogical content, in terms of how it should be implemented with their students. In the Canadian case study, teachers talked about how they should sequence or introduce various features of the application, a discussion that allowed them to reflect on the potential impact of different approaches. In the Singapore case study, teachers were also concerned with how their students would experience the web-based application. This was most apparent during the pilot-testing phase of the design process, where teachers reflected on their students' possible responses to the technology and its contextual relevance within the flow of the lesson design. Thus, an important aspect of the participatory design process is concerned with the opportunities for teachers to reflect on the potential impact of the innovation and how students might experience it (Matuk and Linn 2015).

In both case studies, the teachers considered various ways that the technologies could be implemented with their students, experimenting with enactment. In the Singapore case, in advance of the enactment, the technology was pilot-tested in the field from the perspective of the students. This exercise allowed them to make adjustments to their implementation strategies that could potentially enhance their students' situated experience. Brown (2011) frames teachers' innovative implementation of curriculum designs as a design activity itself (i.e., requiring a sense of action research and evidence-based revision). In this conceptualization of teachers as designers, teachers are regarded as orchestrators or improvisers of pedagogical events (Sawyer 2004). Indeed Brad commented that he had the score in his head when he entered the classroom, implying his intention to improvise from some canonical design. This echoes the assertion of Carlgren (1999), that preparing and planning for teaching "is not something 'behind' or 'beneath' practice or action, but in the action" (pp. 51–52).

## What conditions helped to support teachers?

The Canadian case study provides an example of a researcher team that was engaging with its teacher partners for the first time. Because this endeavor marked the start of a 3-year research collaboration, it was of particular importance for us to cultivate a positive working relationship. The underlying mantra of the researchers was that it was important to be able to demonstrate to the teachers that we were taking seriously their ideas (by embodying their ideas in the design of the technology), or else we risked "breaking faith" with the teachers. In design and technology meetings in which the teachers were not present (i.e., technical meetings), we continually asked ourselves whether software features that we were considering aligned with the design ideas and feedback we had received from the teachers. Similar to the Canadian case, the Future School project was a three-year research partnership. Hence, it was imperative to build good working relations and to create an atmosphere of trust in the collaboration process. Further, one of the project goals was to equip and empower the teachers to take over the design process gradually and subsequently, to be able to train other new teachers who come onboard the Future School project.

Through analysis of the interview data, we have shown that an important aspect of both cases is that the teachers felt empowered and actively engaged in the design process. This section discusses the factors that helped to support inclusive and productive participation for teachers. Below we discuss three conditions that helped to support teachers in the design process: (1) supporting emergent processes, (2) cultivating an atmosphere of trust and partnership, and (3) designing with contextual knowledge.

While some researchers have advocated for a highly facilitated and structured design process (Brandt 2006; Muller and Kuhn 1993), others have maintained the importance of one that is supportive of emergent processes (e.g., Barab 2004). Our case studies reveal ways in which the design process benefited from both structured and adaptive approaches. Clearly, it was helpful for teachers to perceive a well-defined process of design (e.g., brainstorming, scenarios, mock-ups, etc.). On the other hand, teachers felt that the innovation was open to new directions, and that the process was potentially adaptive to new insights. This led to a shared sense of ownership of the direction and responsibility for the outcome.

In the Canadian case study, teachers said that they valued the affirmation that they experienced as members of the team, including feelings of trust and acceptance. They said that they felt that their ideas were heard and not merely "given lip service". For example, when teachers expressed concern that the application would use incentive rewards (an approach that they did not feel motivating for their students), the design team took their point of view seriously and did not create mock-ups with such a feature. In co-design work, it may be necessary for the principal investigator to compromise on some aspects of the research agenda if teachers' ideas are to be taken seriously. It is especially important in design work that involves multiple stakeholder groups, as exemplified by the Singapore case study, where teachers were provided with opportunities to interact with other stakeholders in meaningful contexts.

It is important to provide opportunities for teachers to design with contextual knowledge throughout the entire design process (Barab et al. 2007, Voogt et al. 2015). In the Canadian case study, researchers initially observed the classroom practices of the teachers in order to understand their natural pedagogical sequencing and flow. Following this observation session, design meetings were held in the classrooms of the teachers, and not at a university research lab. The importance of designing within the context of enactment is particularly salient because of the nature of the inquiry environment that we applied and extended. The HelioRoom simulation is physically distributed around the four walls of the classroom, requiring that students move from wall to wall, recording observations on mobile tablets. Being physically present in the classroom space where the technology would be used helped the design team to more concretely envision how enactment would unfold. Designing with contextual knowledge was particularly relevant for the Singapore case study because of its novel context: the landscape features of the mobile trail site were unique and their close ties to activity and curriculum design. Hence, the design team made an intentional decision to conduct some of the meetings at the Fort Siloso location, where physical features of the landscape and how they related to the curriculum content became even more salient. Contextual knowledge of the physical features of the site of learning (e.g., the mobile trail site) enables and empowers teachers to move from discussions of theoretical constructs (e.g., knowledge building principles) to designing with contextual knowledge. Being present at the site affords teachers greater insight into how both curriculum content (e.g., Geography and History) can be mutually informative, and leverage the physical affordances of the learning environment.

The essential conditions supporting teacher in their participation, as found in our case studies, as well as the defined ways teachers participate in the design process clearly resonate with the existing literature. This supports the generalizability of our results, although we realize that that our study was qualitative in nature and our sample size was small. Participatory design initiatives are mostly small-scale processes, which implies that a limited number of teachers are able to contribute to it. This inevitably weakens the strength of research data, but by reporting multiple case studies we aimed to define general applicable themes. Through a variety of data sources, which were collected both during the design process and afterwards, we have started to understand the design participation of teachers. By partly using teachers' self-reported data we investigated the design process from their own perspective. However, results have to be generalized to similar contexts. More research is needed on how teachers can be supported in participatory design in order to define the effects of teachers' contributions on the quality of the instructional design on the one hand, and the quality of the implementation by the teachers on the other hand (Mckenney et al. 2015). Nonetheless, we believe that our two case studies provide some insight to better understanding of a complex mechanism that engages teachers as important participatory designers in the design of technology-mediated learning environments.

## Conclusion

Results from our case studies underscore the need for research teams to include teachers throughout the design process, prioritizing discussions of theory within design activities, allowing opportunities for contextualized investigations, and creating space for teachers to engage with relevant stakeholders. It is important to make room within the design process for teachers to elaborate and reflect on how they will implement the designed curriculum and technology innovations with their students. While it is not trivial to include teachers meaningfully in a design process, their design contributions are vital to their success. Ongoing work should continue to investigate conditions that lead to profitable and mutually beneficial outcomes. We encourage researchers and teachers alike to continue this dialogue to ensure progress toward cultivating productive design environments.

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## References

Barab, S. (2004). Using design to advance learning theory, or using learning theory to advance design. *Educational Technology, 44*(3), 16–20.

Barab, S. (2006). Design-based research: A methodological toolkit. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (pp. 153–170). New York: Cambridge University Press.

Barab, S., Zuiker, S., Warren, S., Hickey, D., Ingram-Goble, A., Kwon, E. J., et al. (2007). Situationally embodied curriculum: Relating formalisms and contexts. *Science Education, 91*(5), 750–782. doi:10.1002/sce.20217.

Bødker, S., & Iversen, O. S. (2002, October). Staging a professional participatory design practice: Moving PD beyond the initial fascination of user involvement. In *Proceedings of the second Nordic conference on human–computer interaction* (pp. 11–18). New York: ACM. doi:10.1145/572020.572023.

Brandt, E. (2006). Designing exploratory design games: A framework for participation in participatory design? In *Proceedings of the ninth conference on participatory design: Expanding boundaries in design* (Vol. 1, pp. 57–66). New York: ACM. doi:10.1145/1147261.1147271.

Brown, A. L. (1992). Design experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings. *The Journal of the Learning Sciences, 2*(2), 141–178. doi:10.1207/s15327809jls0202_2.

Brown, M. W. (2011). The teacher–tool relationship: Theorizing the design and use of curriculum materials. In J. T. Remillard, B. A. Herbel-Eisenmann, & G. M. Lloyd (Eds.), *Mathematics teachers at work: Connecting curriculum materials and classroom instruction* (pp. 17–37). New York: Routledge.

Carlgren, I. (1999). Professionalism and teachers as designers. *Journal of Curriculum Studies, 31*(1), 43–56. doi:10.1080/002202799183287.

Chan, C. K. K. (2008). Pedagogical transformation and knowledge-building for the Chinese learner. *Evaluation and Research in Education, 21*(3), 235–251. doi:10.1080/09500790802485245.

Chen, Y. S., Kao, T. C., & Sheu, J. P. (2003). A mobile learning system for scaffolding bird watching learning. *Journal of Computer Assisted learning, 19*(3), 347–359. doi:10.1046/j.0266-4909.2003.00036.x.

Cobb, P., Confrey, P., diSessa, A., Lehrer, R., & Schauble, L. (2003). Design experiments in educational research. *Educational Researcher, 32*(1), 9–13. doi:10.3102/0013189X032001009.

Cober, R., McCann, C., Moher, T., & Slotta, J. D. (2013, June). Aggregating students' observation in support of community knowledge and discourse. In *Proceedings of the 10th international conference on Computer-supported collaborative learning (CSCL)* (pp. 121–128). New Brunswick: International Society of the Learning Sciences.

Creswell, J. W. (2013). *Qualitative inquiry and research design: Choosing among five approaches*. New York: Sage.

Druin, A. (2002). The role of children in the design of new technology. *Behaviour and Information Technology, 21*(1), 1–25. doi:10.1080/01449290110108659.

Eliasson, J., Pargman, T. C., Nouri, J., Spikol, D., & Ramberg, R. (2011). Mobile devices as support rather than distraction for mobile learners: Evaluating guidelines for design. *International Journal of Mobile and Blended Learning, 3*(2), 1–15. doi:10.4018/jmbl.2011040101.

Hewitt, J., & Scardamalia, M. (1998). Design principles for distributed knowledge building processes. *Educational Psychology Review, 10*(1), 75–96.

Kensing, F., & Blomberg, J. (1998). Participatory design: Issues and concerns. *Computer Supported Cooperative Work, 7*(3–4), 167–185.

Könings, K. D., Brand-Gruwel, S., & van Merriënboer, J. J. G. (2011). Participatory instructional redesign by students and teachers in secondary education: Effects on perceptions of instruction. *Instructional Science, 39*, 737–762. doi:10.1007/s11251-010-9152-3.

Lingnau, A., Harrer, A., Kuhn, M., & Hoppe, U. (2007). Empowering teachers to evolve media enriched classroom scenarios. *Research and Practice in Technology Enhanced Learning, 2*(2), 105–129.

Lingnau, A., Hoppe, H. U., & Mannhaupt, G. (2003). Computer supported collaborative writing in an early learning classroom. *Journal of Computer Assisted learning, 19*(2), 186–194. doi:10.1046/j.0266-4909.2003.00019.x.

Matuk, C., & Linn, M. C. (2015). Technology to support teachers using evidence from student work to customize technology-enhanced inquiry units. *Instructional Science*. doi:10.1007/s11251-014-9338-1.

McKenney, S., Kali, Y., Markauskaite, L., & Voogt, J. (2015). Teacher design knowledge for technology enhanced learning: A framework for investigating assets and needs. *Instructional Science*. doi:10.1007/s11251-014-9337-2.

Moher, T. (2006, April). Embedded phenomena: Supporting science learning with classroom-sized distributed simulations. In *Proceedings of the SIGCHI conference on human factors in computing systems* (pp. 691–700). New York: ACM. doi:10.1145/1124772.1124875.

Muller, M. J., & Kuhn, S. (1993). Special issue on participatory design. *Communications of the ACM, 36*(6), 24–28.

Oshima, J., Oshima, R., Murayama, I., Inagaki, S., Takenaka, M., Yamamoto, T., et al. (2006). Knowledge-building activity structures in Japanese elementary science pedagogy. *International Journal of Computer-Supported Collaborative Learning, 2*(1), 229–246. doi:10.1007/s11412-006-8995-8.

Penuel, W. R., & Gallagher, L. P. (2009). Preparing teachers to design instruction for deep understanding in middle school Earth science. *The Journal of the Learning Sciences, 18*(4), 461–508. doi:10.1080/10508400903191904.

Penuel, W., Roschelle, J., & Shechtman, N. (2007). Designing formative assessment software with teachers: An analysis of the co-design process. *Research and Practice in Technology Enhanced Learning, 2*(1), 51–74.

Penuel, W. R., Fishman, B. J., Cheng, B. H., & Sabelli, N. (2011). Organizing research and development at the intersection of learning, implementation, and design. *Educational Researcher, 40*(7), 331–337.

Peters, V. L., & Slotta, J. D. (2008). Co-designing a knowledge building activity with secondary school biology teachers. Retrieved from http://www.ikit.org. Accessed 31 March 2014.

Peters, V. L., & Slotta, J. D. (2009). Co-designing curricula to promote collaborative knowledge construction in secondary school science. In *Proceedings of the 9th international conference on Computer-supported collaborative learning* (pp. 204–213). New Brunswick: International Society of the Learning Sciences.

Reiser, B. J., Spillane, J. P., Steinmuller, F., Sorsa, D., Carney, K., & Kyza, E. (2000). Investigating the mutual adaptation process in teachers' design of technology-infused curricula. In B. Fishman & S. O'Connor-Divelbiss (Eds.), *Fourth international conference of the learning sciences* (pp. 342–349). Mahwah, NJ: Erlbaum.

Rogers, Y., & Price, S. (2008). The role of mobile devices in facilitating collaborative inquiry in situ. *Research and Practice in Technology Enhanced Learning, 3*(3), 209–229.

Roschelle, J., Penuel, W. R., & Shechtman, N. (2006). Co-design of innovations with teachers: Definition and dynamics. In *Proceedings of the international conference of the learning sciences* (pp. 606–612). New Brunswick: International Society of the Learning Sciences.

Sawyer, R. K. (2004). Creative teaching: Collaborative discussion as disciplined improvisation. *Educational Researcher, 33*(2), 12–20.

Sawyer, R. K. (2011). What makes good teachers great? The artful balance of structure and improvisation. In R. K. Sawyer (Ed.), *Structure and improvisation in creative teaching* (pp. 1–24). New York: Cambridge University Press.

Scardamalia, M., & Bereiter, C. (2003). Knowledge building. In J. W. Guthrie (Ed.), *Encyclopedia of education* (pp. 1370–1373). New York: Mcmillan Reference.

Scardamalia, M., & Beretier, C. (2006). Knowledge building: Theory, pedagogy, and technology. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (pp. 107–123). New York: Cambridge University Press.

Schuler, D., & Namioka, A. (Eds.). (1993). *Participatory design: Principles and practices*. Hillsdale, NJ: Lawrence Erlbaum Associates Inc.

Sharples, M., Taylor, J., & Vavoula, G. (2007). A theory of learning for the mobile age. In R. Andrews & C. Haythornthwaite (Eds.), *The Sage handbook of e-learning research* (pp. 221–247). London: Sage.

Shrader, G., Williams, K., Lachance-Whitcomb, J., Finn, L. E., & Gomez, L. (2001, April). *Participatory design of science curricula: The case for research for practice*. Paper presented at the Annual Meeting of the American Educational Research Association, Seattle, WA. Retrieved from http://www.letus.org/PDF/ShradervaeraSpencer.pdf. Accessed 7 July, 2014.

Spikol, D., Milrad, M., Maldonado, H., & Pea, R. (2009, July). Integrating co-design practices into the development of mobile science collaboratories. In *Ninth IEEE international conference on advanced learning technologies* (pp. 393–397). IEEE. doi:10.1109/ICALT.2009.175.

Squire, K., & Klopfer, E. (2007). Augmented reality simulations on handheld computers. *The Journal of the Learning Sciences, 16*(3), 371–413. doi:10.1080/10508400701413435.

Suchman, L. (1993). Forward. In D. Schuler & A. Namioka (Eds.), *Participatory design: Principles and practices* (pp. vii–ix). Hillsdale, NJ: Lawrence Erlbaum Associates Inc.

Svihla, V., Reeve, R., Sagy, O., & Kali, Y. (2015). A fingerprint pattern of supports for teachers' designing of technology-enhanced learning. *Instructional Science*. doi:10.1007/s11251-014-9342-5.

Toronto District School Board. (2007). Toronto District School Board ICT Standards: Digital learning for kindergarten to grade 12. Resource document retrieved from http://www.tdsb.on.ca/wwwdocuments/

programs/computers_in_schools/docs/TDSB-ICT_Standards_Bookmarked.pdf. Accessed 31 March, 2014.

Vavoula, G., & Sharples, M. (2007). Future technology workshop: A collaborative method for the design of new learning technologies and activities. *International Journal of Computer-Supported Collaborative Learning, 2*(4), 393–419.

Voogt, J., Laferrière, T., Breuleux, A., Itow, R., Hickey, D., & McKenney, S. (2015). Collaborative design as a form of professional development. *Instructional Science*. doi:10.1007/s11251-014-9340-7.

Yin, R. K. (2009). *Case study research: Design and methods*. Thousand Oaks, CA: Sage.

Yoon, S. A., Liu, L., & Goh, S. E. (2009, June). Exploring the process of convergent adaptation in technology-based science curriculum construction. In *Proceedings of the 9th international conference on computer-supported collaborative learning* (pp. 272–281). New Brunswick: International Society of the Learning Sciences.

Zhang, B., Looi, C. K., Seow, P., Chia, G., Wong, L. H., Chen, W., et al. (2010). Deconstructing and reconstructing: Transforming primary science learning via a mobilized curriculum. *Computers & Education, 55*(4), 1504–1523. doi:10.1016/j.compedu.2010.06.016.